New and Innovative Technologies for Mixed Waste Treatment

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Permits and State Programs Division

Contents

Introduction

This report is the culmination of a project completed under the National Network for Environmental Management Studies (NNEMS) Fellowship program in the summer of 1997. The NNEMS program is a cooperative educational program between EPA and college level environmental programs around the country. This particular research project was completed by a fellow from the University of Michigan, School of Natural Resources and Environment under direction of EPA Office of Solid waste, Permits and State Programs Division.

The project involved identifying and reporting on new and innovative technologies for the treatment of mixed waste. The resulting report summarizes seventeen different technologies that either hold potential for mixed waste treatment or currently treat mixed waste. This report does NOT include evaluations or detailed information on mixed waste technologies. Instead, it is a summary of the seventeen separate technologies, compiled with two general goals in mind. The first goal is to give the reader background information, in relatively simple terms, on an individual technology and serve as a quick reference or starting point for research on that technology. The second goal is to provide a sense of the types of technologies under development for mixed waste treatment.

Disclaimer

EPA does not endorse or sponsor any of the technologies included in this report. Any apparent preferential representation of a technology is unintended and most likely results from variation in the accessability of information on each technology.

This report is the product of approximately three months of work. All mixed waste treatment technologies identified in that time span are included in the report. However, that does not mean this is an all inclusive or exhaustive list of existing mixed waste treatments. New technologies are being introduced and old ones modified continuously. This report is intended to be viewed as a quick guide and summary of several mixed waste technologies.

Many of the technologies included in the report are unique and patented by an organization. Others are not patented, but only a few organizations are pursuing the technology. As a result, for some technologies the summary is heavily dependent on information collected from an individual company, vendor or research organization. The information in this report has not been evaluated for accuracy. To check the accuracy of the information included or obtain detailed information, contact the name listed with each technology.

Report Format/Organization

The seventeen technologies included in this report are separated into four categories according to how they manage the waste. These four categories are entitled: separation technologies, stabilization/immobilization technologies, destruction technologies and combinations of those mentioned above. Each of these categories has a short introduction preceding the technology summaries.

As mentioned above this report summarizes seventeen different treatment technologies. The information in each technology summary is organized into three separate sections. These sections are: technology description; acceptable wastes; and status of technology.

The technology description section gives the reader background information on how the technology works. This section is further broken down into three sub-sections: principles; process; and result. A summary of the scientific principles on which the technology is based is found in the PRINCIPLES sub-section. A quick description of the set up of the technology itself is presented in the PROCESS sub-section. Information on what comes out of the system on the product-end is summarized in the RESULTS sub-section.

The following section is entitled acceptable wastes. In three subsections it describes the types of wastes that can be treated with each process. The three subsections are PHASE, HAZ and RAD. The PHASE subsection delineates the phase of waste that can go into this process. For the purpose of this report, this not only includes information on solid, liquid and gas phases, but is extended to include aqueous waste streams, sludges and slurries. HAZ and RAD summarize the RCRA hazardous materials and the radionuclides that can go through the system.

The seventeen technologies included in this report are in various stages of development. The section on status gives the reader an idea of the degree of development for each technology. Each technology has a two word description of the status. These categories are (ranging from least developed to most developed):

> **Research Phase**- technologies whose theoretical underpinning are still being tested in a laboratory.
> **Bench Scale**- technologies that have completed the research phase and are being tested on a small scale, usually in a research laboratory.
> **Demonstration w/ Surrogates**- technologies that have been proven with a lab scale model. Tests are being run on a large scale model with hazardous substances and surrogates for the radionuclides.
> **Demonstration w/ Waste**- same as ‘Demonstration with Surrogates’, but the actual mixed waste is treated.
> **Commercially Available**- technologies that are available for treatment of commercially generated wastes.

After the categorization of status there is a subsection on projects. This subsection gives the reader a quick update of the most recent mixed waste treatment projects undertaken with each technology. Following the projects sub-section is information on persons to contact with questions or requests for additional information.

<u>Research Methods</u>
Several different sources were utilized to identify emerging mixed waste technologies. Many of these technologies were identified through the EPA SITE, VISITT and CLU-IN databases.

Several technologies were identified through research on the Internet. Others were located in proceedings from conventions on mixed waste.

For specific information on each technology, it was necessary to track down organizations presently researching the technology. By directly contacting the developers and vendors of the technologies I was able to request company information on the technology and gather information through personal interviews. The bulk of the information in this paper was gathered through personal contact with technology vendors.

In the interest of presenting information that is accurate and fairly represented, I tried to gather information from several different sources on each technology. There are cases, however, where only one research and development organization was identified for a technology. Since many of these technologies are newly available or under development, few evaluations have been completed. In these cases, the technology summaries are necessarily dependent on the information provided by one organization.

1. SEPARATION / REMOVAL TECHNOLOGIES

Separation technologies treat mixed waste by separating the hazardous and radioactive components. These technologies do not destroy the hazardous component or mitigate the danger associated with the radioactive portion. These technologies simply facilitate further treatment by separating the hazardous and radioactive components.

1.1 Low Temperature Thermal Desorption

Technology Description:

PRINCIPLE
This process separates hazardous organics and radionuclides by taking advantage of the disparity between the boiling points of organic and inorganic substances. The boiling points of organic substances are typically below about 300° F, whereas the boiling points of inorganic substances can be in the thousands of degrees. Exposing waste streams to moderate temperatures will convert the organic contaminants to their gaseous form. This separates the organics from the inorganic waste components which includes the radionuclides. The inorganic portion of the waste remains in its solid form. The volatilized organics are transported away from the rest of the waste via airflow of an inert gas such as nitrogen or by a vacuum system. Once separated from the inorganics, the organics can be condensed back into liquid form or destroyed by oxidation.

Low temperature thermal desorption (LTTD) systems do not operate at a high enough temperature to actually destroy organics. They simply separate the organics from the non-organic component and collect the organics in a gas treatment system.

PROCESS
McLaren Hart has developed and patented a low temperature thermal desorption unit. The McLaren Hart system employs infrared heating and a vacuum system. Wastes are placed in a static bed and heated from the top by infrared radiation. Air is drawn downward through the bed, picking up volatilized compounds and transporting them to the gas treatment system. The vacuum system also lowers the ambient pressure of the system, allowing the organic substances to vaporize at lower temperatures.

This particular system design is compact enough to be mounted on a trailer and transported from site to site. Mixed waste generators must obtain all of the appropriate permits for McLaren Hart to treat on site.

OHM Remediation Services operates the X-TRAX system. X-TRAX is an indirect fired rotary kiln. In this design one barrel is situated within another barrel. Waste is loaded into the internal barrel and the heat source for the desorption is located in between the two barrels. When heat is applied to the system the organics are volatilized without ever directly contacting the heat source.

RESULT

This process separates mixed waste into its radioactive and hazardous components. Most of the radioisotopes remain in their solid form while the hazardous organics are collected in their gaseous or liquid form. Neither the hazardous nor the radioactive products have been treated or stabilized in any way. However, by separating these two components, each can be treated appropriately without the complication of managing both simultaneously.

Special consideration must be given to tritium contaminated wastes. Although the temperature in this system is low enough to keep most radionuclides in their solid form, tritium is volatilized and separated from the solid waste matrix. The gaseous tritium is caught in the condensate, which is then run through a exchange resin bed to capture and separate the tritium from the rest of the organics in the condensate.

Acceptable Wastes:

PHASE

McLaren Hart accepts only solid and semi-solid waste with no free liquids, for treatment in their unit. They do not process liquid waste for two reasons. First it requires much more energy to volatilize liquids (especially water) than residual organics, and second, the treatment of liquids carries a large particulate load into the off-gas treatment system. This quickly exhausts the system, reducing its length of use.

HAZ

LTTD is designed to remove volatile and semi-volatile organic compounds from mixed waste. McLaren Hart company materials indicate that they can effectively remove pesticides, PCBs, VOCs, SVOC, dioxins and mercury from solid waste matrices. The following is a list of chemicals that have been successfully removed from soils and other wastes. (Note: this is not an exhaustive list.):

1,1,1-Trichloroethane	Methoxychlor
1,1-Dichloroethane	Methylene Chloride
Acetone	PCE
Carbon tetrachloride	TCE
Chlordane	Tetrachloroehtylene
Chloroform	Toluene
DDT	Trichloroethylene
DDE	other chlorinated organics

RAD

McLaren Hart has treated mixed waste containing the following radionuclides:

Americium (Continued on next page)
Plutonium
Strontium
Tritium
Uranium (233,234,235,238)

Status: **Commercially available.**

There are several organizations doing work on thermal desorption technologies; however, the field is much more limited for those treating mixed waste. Research identified three organizations pursuing LTTD for mixed wastes. They are McLaren Hart, IT Corporation, and OHM Remediation Services. Most likely, this is not an exhaustive list. The following is a summary of the status of this technology for each vendor.

McLaren Hart:

McLaren Hart has, to date, focused most of their efforts on treatment of remediation soils contaminated with both radionuclides and RCRA hazards. Recently, they have expanded their system to process wastes; successfully treating coal tar, tank bottom sludge and filter cake. While non of these are mixed waste it does demonstrate McLaren Hart's ability and interest in treating non-soil substances.

<u>PROJECTS</u>
In the summer of 1997 McLaren Hart will complete a project treating approximately four thousand cubic yards of soil from Rocky Flats Site in Denver, CO. This soil was contaminated with 1,1,1-trichloroethane, 1,1-dichloroethane, acetone, carbon tetrachloride, chloroform, methylene chloride, PCE, TCE and toluene with radioactive contamination from Americium, Plutonium, Strontium, Tritium and Uranium.

McLaren Hart is planning a project with NuWorld Technologies of Houston, Texas to treat mixed waste. The waste from NuWorld Technologies waste is comprised of debris and soil mixed with crushed liquid scintillation vials. This material will likely be contaminated with toluene, xylene, and tritium, among other things. Representatives from NuWorld Technologies are meeting at Rocky Flats in mid August of 1997 to inspect the system in place there and begin planning for the work to be done.

For more information contact:
Jeff O:Ham, Senior Project Manager and Technical Director
McLaren Hart 704/587-0003

IT Corporation:

IT Corporation has done extensive testing in the thermal desorption arena. Their services on mixed waste consulting and treatment are currently available, however, they do not operate a system of their own and must contract out a thermal desorption unit to complete the work.

PROJECTS

IT Corporation is currently involved in a project to treat mixed remediation wastes from Tinker Air Force Base in Oklahoma. This is the site of an old land fill where radium and various solvents have commingled in the soils. The site is contaminated with benzene, toluene, methyl ethyl ketone, methyl isobutyl ketone and xylene from degreasing and paint removal operations; as well as radium from painting aircraft instrument dials. The soil has been excavated from the site and is awaiting treatment. IT Corporation is planning on undertaking treatability studies and preliminary cost estimates soon.

For more information contact:
Stuart Shealy
Engineering Section Manager of Technology Applications Lab
IT Corporation
304 Directors Drive
Knoxville, TN 37923
423/694-7447

The Headquarters for this organization is located at:
2790 Mosside Blvd.
Monroeville, PA 15146

OHM Remediation Services:

OHM operates a rotary kiln LTTD unit. In the early nineties this system was used to treat mixed wastes from a site Y12 at Oak Ridge National Laboratory. Since that time the X-TRAX system has operated mostly on hazardous substances extraction and not mixed waste treatment. However, the technology has been demonstrated on mixed waste and is available for mixed waste treatment. OHM can be contacted for more information.

For more information, contact:
Dennis Galligan
Vice President of Corporate Technology Services
OHM Remediation Services Corp
PO Box 551
Findlay, OH 45839
419/425-6105

1.2 Magnetic Separation (MAG*SEP Process)

Technology Description:

PRINCIPLES
This processes uses ion exchange principles and magnetized particles to separate heavy metals and radionuclides from water and aqueous stream wastes. Selective Environmental Technologies, Inc. (Selentec) has developed and patented a system called the MAG*SEP particles. These very small particles (ranging from 70 to 300 microns) have a core of magnetite with an acrylic coating. A functionalized resin that is similar to those used in ion exchange columns is applied to the acrylic. This resin selectively adsorbs heavy metal and radionuclides onto its surface. The particles and contaminants are then removed from the waste stream by a magnetic filtration system.

The selectivity of the resin coatings results in removal of only specific contaminants. Selentec has a vast array of functional resins that can be used in combination or separately to selectively remove metals from waste streams. Wastes can be cycled through the system more than once to sequester and separate different contaminants with each run. The high selectivity of the functionalized resins makes it possible to effectively remove low level contaminants even in the presence of natural groundwater metals that would otherwise compete for the resin.

Depending on those metals present, this technology can be successful in separating radioactives from RCRA metals. The presence of some organic contaminants does not interfere with the function of certain MAG*SEP particles. As a result, removal of radionuclides from hazardous organics can be achieved. The ability to separate RCRA metals, radioactives and hazardous organics is case specific, and requires consultation for each particular waste stream.

PROCESS
Each waste stream requires a different combination of particles for successful treatment. Scientists at Selentec characterize the waste contaminants, then manufacture the specific type and combination of particles needed for treatment. Selentec can install permanent or semi-permanent treatment systems or operate their mobile unit on site. They can also manufacture and ship particles to clients for use in their own facilities.

After treatment, contaminated particles can be regenerated for reuse or disposed in a stable final waste form.

RESULT
Depending on the components of the waste, this technology could result in separation of RCRA metals and radioactives. It is possible to remove either the radioisotopes, the metals, or both from mixed waste streams.

After treatment the metals and radionuclides are isolated on the particles or in the acidic particle regeneration solution. MAG*SEP is working on a complimentary technology that utilizes an electrochemical cell to precipitate the metals out of the acid solution. As a result, the acid solution can be reused and the volume of the waste is further reduced.

Acceptable Wastes:

PHASE

This technology works on aqueous stream and slurried wastes with heavy metal and radionuclide contamination. It is effective on liquid slurries with up to 50% suspended solids.

In some cases, organic contaminants do not interfere with the MAG*SEP process and therefore the technology can be used regardless of their presence.

HAZ/RADS

This process is designed to remove metals from waste. It can remove the following metals, whether radioactive or not:

Arsenic	Iron	Ruthenium
Bismuth	Lead	Selenium
Cadmium	Manganese	Silver
Cesium	Mercury	Strontium
Chromium	Molybdenum	Technetium
Cobalt	Nickel	Thallium
Copper	Palladium	Titanium
Gold	Platinum	Zinc
Iodine	Radium	All actinides (atomic numbers 89-103)

Status: **Commercially available.**

At present, this technology is available for commercial waste generators; however, Selentec does not have a treatment facility and their mobile unit is not yet operational (as of summer 1997). Therefore, only if the generator has their own facility or would be willing to install one (with inexpensive components), would this technology would be commercially available to them.

PROJECTS

This technology has been utilized on several projects. For example, it was employed to remove iron and copper from the Berkeley Pit water, to treat groundwater from the Savannah River Site (SRS), to remove metal contaminants from tritiated water at SRS, and to remove radionuclides from milk in the Chernobyl region.

For more information on this technology, contact:

Steve Weldon

Business Development Manager

Selentec, Inc.
8601 Dunwoody Place, Suite 302
Atlanta, GA 30350-2509
770/640-7059

1.3 Supercritical Carbon Dioxide Extraction (solvent extraction)

Technology Description:

PRINCIPLE
This process works a lot like an intense washing process extracting hazardous organics from soils and debris. Carbon dioxide is an excellent solvent for organic contaminants when heated above 90° F and compressed to over 1,500 psi. The elevated pressure helps to work the carbon dioxide solvent into the waste matrix or debris and extract the organic contaminants. The organic contaminants go into solution in the carbon dioxide fluid, separating from the radioisotopes which stay in their solid form. The organics are removed from the supercritical fluid by reducing the pressure in the system and condensing the organics. The result is a separation of the radioactive and hazardous organic components.

PROCESS
Carbon dioxide is heated and pressurized, then pumped through a chamber containing the waste materials to be treated. Here it extracts the organic substances from the waste material. The supercritical carbon dioxide fluid then flows into an expansion chamber where the pressure decreases. The pressure change causes the carbon dioxide to go into gas phase and the dissolved organics to condense to their liquid form, resulting in separation of the hazardous and radioactive components.

RESULT
Supercritical carbon dioxide extraction (SCDE) separates the radioactive and hazardous components. After treatment the radioisotopes remain in the initial waste matrix which no longer contains hazardous organic materials. The extracted hazardous organics are condensed into their liquid form. This material will still exhibit its hazardous characteristics. Therefore, it must be treated before disposal.

Acceptable Wastes:

PHASE

This technology can effectively remove hazardous organic substances from solids and debris, including rags, coveralls, paper, plastics and surgeons' gloves. This treatment technology is not effective on straight liquids. SCDE is, however, effective on waste matrices with high moisture levels such as soils.

HAZ

This technology was developed to extract volatile and semi-volatile organic compounds from mixed waste streams. Rocky Flats has performed research on this technology. They have extracted hazardous materials from waste, however without the presence of radioactives. They have successfully extracted the following substances (Note: this is not an exhaustive list.):

Acetone	1,1,1-Trichloroethane
Biphenyl	1,2,4-Trichloroethane
Carbon Tetrachloride	Methylene Chloride
1,2-Dichlorobenzene	

RADS

Idaho National Engineering Laboratory (INEL) scientists believe this process is capable of treating alpha emitting radioactives and will be particularly suitable for plutonium contaminated wastes. INEL and Rocky Flats are focusing their attention on those wastes that would be found at Rocky Flats. The predominant radionuclide is plutonium 239, as well as a mixture of Pu-239 decay products.

Status: **Demonstration Phase.**

PROJECTS

INEL has been developing this technology and plans to apply it to mixed waste generated at Rocky Flats in Colorado. INEL has procured a 16 gallon system for mixed waste treatment, but they have yet to be permitted for mixed waste treatment.

Rocky Flats and the University of Colorado at Boulder have done extensive research to determine the suitable waste matrices for SCDE treatment. However, work remains to be done on radionuclide partitioning (i.e. the behavior of the radionuclides inside the reaction vessel). This work must be complete for the Rocky Flats system to be permitted. Rocky Flats and INEL are currently conducting this research on a smaller device at INEL. This research should be complete in 1998. The information gathered will then be used to support permitting activities for the system at Rocky Flats.

It is unclear whether and how this technology will become commercialized.

For more information, contact:

Charles Brown
Principle Investigator

Rocky Flats
Colorado
303/966-5277

Michael Connolly
Mixed Waste Focus Area Project Director
Idaho National Engineering Laboratory
Idaho
208/526-0238

1.4 Supercritical Carbon Dioxide Extraction (metals and radionuclides)

Technology Description:

This technology uses the same equipment as SCDE for solvent extraction. In this case, metals and radionuclides are removed from the waste stream instead of the organic solvents. To accomplish this, a chelating agent is bonded to the surface of metals and radionuclides. This chelating agent bonds strongly to the metals, covering the metal with a non-polar compound. The metal/chelate combination is easily dissolved in the supercritical fluid. When the pressure on the system is decreased the carbon dioxide transforms into its gas phase, forcing the chelated metals out of solution.

Acceptable Wastes:
Current research at University of Colorado will determine what metals and radionuclides can be extracted from waste streams using this process.

Status: **Research Phase.**

This technology is still in its preliminary phases of research. Wendy Andersen at the University of Colorado, Cooperative Institute for Research in Environmental Sciences (CIRES) has recently begun research on this technology. As of the summer of 1997, she is looking at the solubilities of different chelates in supercritical carbon dioxide fluid.

Similar work is being done by Chien Wai, University of Idaho, using fluorinated chelates, because they are more soluble in carbon dioxide.

Ken Raymond of the University of California, Berkley, is involved in ongoing research to identify strong chelating agents for the actinides (elements with atomic number 89-103).

For more information contact:
Wendy Andersen
University of Colorado

Cooperative Institute for Research in Environmental Sciences
Boulder, CO
303/492-8624

1.5 Bioprocessing

Technology Description:

The Bioprocessing group at Pacific Northwest National Laboratory (PNNL) is conducting research on the use of bacteria to extract metals out of solution by reducing them to an insoluble form. Specifically, they are looking at the bioprecipitation of uranium from aqueous wastes by reducing the soluble uranium (VI) to insoluble uranium (IV). There are several species of bacteria that perform uranium reduction. For their research the PNNL Bioprocessing group have chosen *Shewanella alga.*

<u>RESULT</u>
This process selectively removes uranium by reducing it to uranium (IV) which forms uranium oxide or urinite and precipitates out of solution. The solid precipitate is easily collected from the aqueous solution.

Acceptable Waste:
This type of technology could treat aqueous wastes contaminated with dissolved uranium. Commercially generated mixed waste does not often contain uranium. However, in the interest of representing as many technologies as possible, it was included in this report.

Status: **Research stage.**

The Bioprocessing group of PNNL recently published a paper on the kinetics of uranium reduction. Information on kinetics is necessary for the application of this research to remediation. This research expands on research completed by several scientists.

U (VI) reduction has been an area of research for many years. PNNL is not the only entity researching this subject. The technology was originally developed to remove dissolved U (VI) from water used to wash uranium contaminated soils. The Department of Energy has chosen not to pursue soil washing as remediation solution for uranium contaminated soils. As a result, this technology has not been aggressively pursued. However, this research is still relevant in many areas. It can be used for the treatment of mine drainage, contaminated groundwater, or leachate from uranium tails.

For more information contact:
PNNL Bioprocessing Group
http://terrassa.pnl.gov:2080/bioprocess

2. STABILIZATION / IMMOBILIZATION TECHNOLOGIES

Stabilization technologies stabilize or immobilize mixed waste without separating the hazardous and radioactive components. These technologies are most suitable for wastes containing both RCRA metals and radionuclides. They are less appropriate for mixed waste containing organic hazardous substances.

2.1 MAECTITE Process

Technology Description:

PRINCIPLE

The patented Maectite process is a chemical stabilization process for inorganics, including hazardous and non-hazardous metals as well as radionuclides. Inorganic contaminants are converted into a stable form by chemically transforming them into hard or superhard minerals. In hard and superhard minerals the ions in the mineral are bonded so tightly together that random thermal motion is limited. This results in superior stability and lower solubility. The resulting mineral form is a crystalline compound that is microscopic in size. It is chemically stable, has a low solubility and does not crush or degrade from physical force.

The goal of this treatment process is to incorporate the inorganic materials into an apatite crystal. Apatite is a crystal formed from calcium, fluoride and phosphate. The actual chemical reactions themselves are quite complex. For further information on this subject, contact Sevenson Environmental Services, Inc.

PROCESS

By characterizing the components of the waste stream, Sevenson scientists can determine the most insoluble mineral form into which the waste can be incorporated. The scientists at Sevenson then determine the specific combination of reactants as well as the conditions (i.e. pH, pressure, etc.) necessary to create the chosen mineral form. Once this determination has been made, reagents are combined and conditions manipulated until the inorganic contaminants have been fully incorporated.

Sevenson operates a mobile unit that is transported on site as needed. The technology can also be modified and installed permanently on site.

RESULT

The treated material appears similar in form to the untreated material. The resulting mineral compounds are microscopic and independent of one another; they do not form aggregates and are not monolithic in structure. As a result, the treated waste maintains its original form with the metal contaminants still present, only now in the form of microscopic crystals. After treatment

RCRA metals no longer exhibit their toxic characteristics.

The radioactive components are transformed into mineral species that remain radioactive. This treatment immobilizes the radionuclides and reduces leaching, but does not render them non-radioactive.

Acceptable Wastes:
Maectite process was developed for the treatment of soils contaminated with RCRA metals. Only recently have they begun to apply this technology for the stabilization of radioactive species.

PHASE
This process can treat soils, solids, sludges or aqueous wastes contaminated with metals.
For aqueous streams, the metals are brought out of solution then handled as a solid waste.

HAZ
The Maectite process was originally designed for the treatment of lead, however it can immobilize and ›render non-hazardous= the following metals:

Arsenic	Cyanide
Barium	Lead
Cadmium	Nickel
Chromium	Selenium
Copper	Sulfur

Although, some trace organics can be treated with this process, Sevenson does not pursue this activity. This treatment process utilizes phosphates to create the mineral final waste form. Phosphates and organics can react to create organophosphates, which are extremely dangerous substances.

RADS
Sevenson has only recently begun applying their technology to radioactive materials. They have completed two bench scale projects treating radioactively contaminated soils from New Jersey and Ohio. The dominant radioactives were uranium and thorium, however, several decay products were also present. All of the following radionuclides were stabilized.

Lead-210	Thorium-228
Lead-212	Protactinium-231
Bismuth-211	Thorium-234
Bismuth-214	Uranium-235
Francium-223	Cesium
Radium-223	Technicium
Radium-224	Thorium-227
Radium-226	Cerium
Actinium-227	Cobalt

Status: **Demonstration with Waste.**

Sevenson has performed over 1,000 treatability tests and conducted over 200 treatment projects for the immobilization of RCRA and other metals in soils. Work on radionuclides and mixed waste is more limited. In 1996 Sevenson completed two research projects on soils from New Jersey and Ohio contaminated with Uranium and Thorium as well as their decay products. This treatment significantly reduced radioactive leaching of all radionuclides present.

<u>PROJECTS</u>
Sevenson has also completed work on soils from Savannah River, INEL and Oak Ridge National Laboratory. They are currently writing technical reports for this work.

For more information contact:
Sevenson Environmental Services, Inc.
9245 Calumet Avenue, Suite 101
Munster, IN
219/836-0116

2.2 Mercury Stabilization (De-Merc)

Technology Description:

<u>PRINCIPLES</u>
The DeMerc process is a patented technology developed by Nuclear Fuel Services, Inc. Proprietary reagents convert mercury from hazardous to non-hazardous forms. The final waste form takes the shape of either a monolithic solid, or a press cake depending on the dominant form of mercury present.

<u>PROCESS</u>
Waste is shredded, mixed with water, then combined with NFS's patented reagents. During treatment, mercury is immobilized into a non-hazardous form, without redistributing radioisotopes. Because this is a proprietary process Nuclear Fuel Services, Inc. preferred not to divulge details on the reagents or final form of the treated waste. For more information call NFS directly.

In addition to mercury stabilization, this technology can immobilize other hazardous metals such as cadmium, silver and lead.

RESULT

This treatment process results in a non-hazardous waste form that achieves the TCLP limit as well as the LDR for mercury. The final product is a solid in one of two forms depending on the type of mercury present. For waste streams high in elemental mercury concentrations, the result is a solid, monolithic waste form. Wastes with a lower elemental mercury concentration end up in a solid press cake.

Acceptable Wastes:

PHASE

The proprietary De Merc process can treat mercury contaminated solids, aqueous and organic bearing solutions.

HAZ

This process is suitable for both low and high concentration of mercury. Elemental and organometallic mercury can be rendered non-hazardous with this process. Light organics and other contaminants do not interfere with the treatment process. For example, this process successfully treated mercury contaminated liquid scintillation fluids containing over 50% organics.

RADS

The process operates completely independently of the presence of radionuclides. As a result, the process should be capable of treating all types of radioactives.

Status: Commercially available.

NFS operates a permitted facility in Erwin, TN. This facility is presently used for processing mixed waste generated by NFS. It is prepared to treat commercially generated mixed waste. NFS is currently soliciting proposals for treatment.

PROJECTS

In 1995 this system successfully treated approximately 250 barrels of mercury contaminated mixed waste generated by NFS. The waste included lab trash contaminated with mercury, one gallon bottles of mercury thiocyanate and elemental mercury mixed with insulation and trash from a nuclear fuel production building. The treatment achieved a volume reduction of 50% (to 122 barrels).

NFS has recently completed research projects to determine the efficacy of the DeMerc process on two different mercury bearing waste streams. The first project involved mixed waste containing elemental mercury and tritium. The amalgam final waste form passed the TCLP test with a comfortable margin. The second project was performed on aqueous and organic-bearing mercury solutions with trace amounts of tritium. Liquid wastes from this process contained less than 0.02 mg/L of mercury and the solid product passed the TCLP leachate test to three orders of magnitude below the requirement.

For more information, contact:

Bala Suresh
Process Engineer
Nuclear Fuel Services, Inc.
1205 Banner Hill Road
Erwin, TN 37650
423/743-2501

Steve Schutt
3945 Holcomb Bridge Road, Suite 202
Norcross, GA 30092
770/447-6956

2.3 Microwave Melting

Technology Description:

PROCESS
This is an Ain drum@ solidification process. A container is filled part way with inorganic materials and a silica compound. The system is not specific to any particular size or shape container, however, some care should be exercised, as this will become the final waste form container. An initial melt is started at the bottom of the final vessel or container by directing microwave radiation on the inorganic materials. Once heated to the molten phase, waste and more silica compound are added. The process alternates the addition of more wastes with heating by microwave radiation until the container is full. Once the microwave energy is turned off the melted materials solidify into a synthetic non-leaching crystalline material suitable for final disposal.

Microwave radiation can travel several hundred feet. As a result, this treatment can be applied from a remote site if the materials to be treated pose a danger to human health.

Acceptable Waste:
Microwave melting can be used on inorganic wastes contaminated with radionuclides. This system is not suitable for treatment of organic wastes.

PHASE
Preliminary research indicates that this process can treat all kinds of inorganics waste, provided volatility is not a problem.

HAZ
Microwave melting can successfully immobilize RCRA metals and other inorganic substances.

RADS
This system can treat mixed wastes with a wide range of radioactivity.

Status: **Demonstration with waste (project terminated).**

EET Corp has done some work for the Department of Energy's Oak Ridge National Laboratory. They achieved a volume reduction of 8:1. The project was put on hold when they found out that their storage area was not acceptable for the radioactivity that they had planned to put into it.

At present EET does not have any mixed waste projects going. They operate a full scale facility, but it does not have an NRC permit and therefore only operates as a cold facility.

Oak Ridge National Laboratory was conducting a microwave melting project for mixed waste stabilization. The project was completed and papers have been published, however, the laboratory is no longer pursuing this technology.

2.4 Phosphate Ceramic Final Waste Forms (Ceramicrete)

Technology Description:

PRINCIPLE

The ceramic final waste form is a proprietary process of Argonne National Laboratory which incorporates inorganic waste materials into a monolithic ceramic material. This ceramic material is a stable final waste form that immobilizes inorganic materials through chemical fixation and physical encapsulation. In this process inorganic materials are converted to inorganic phosphates. These phosphates are virtually insoluble and become integrated into the phosphate network of the ceramic. These inorganic contaminants are further immobilized by being physically encapsulated within the dense matrix of the ceramic.

PROCESS

In this process magnesium oxide, acid phosphates and water are combined to form a thick slurry. This slurry can be poured into a final waste container for shaping or simply left to set in the original container. After two hours at room temperature, this substance hardens into a phosphate ceramic. The phosphate ceramic is a stable, monolithic final waste form similar in composition to dental cement.

Wastes are incorporated into the reagents before they are combined. This can happen two different ways. Solids wastes are mixed with the solid reagent, magnesium oxide; liquid wastes are used in place of the water.

RESULT

The result is a final waste form that immobilizes heavy metal contaminants including RCRA metals and radionuclides. Since the slurry takes the shape of its container, the final form can be shaped to facilitate storage. The final waste form can contain up to 50-75% waste with no major increase or decrease in volume. The resulting ceramic has a compression strength two to three times higher than Portland cement and is called Ceramicrete.

There are no secondary wastes to this treatment technology.

Acceptable Wastes:
This stabilization/immobilization process is most amenable to fly ash and bottom ashes.

<u>PHASE</u>
Ceramicrete can immobilize most inorganic wastes in the form of solids, liquids and sludge.

<u>HAZ</u>
The Ceramicrete process treats inorganic materials. The process has been used effectively to treat waste streams containing lead, cadmium, chromium, mercury, silver and barium.

This process has incorporated small quantities of organic materials into the ceramic. However, wastes with high organic content can not be treated with this process.

<u>RAD</u>
So far, this technology has successfully immobilized these radionuclides:

Cesium-137
Uranium-238
Uranium-235
Americium-241.

This process should be suitable for most radionuclides. However, more research is required to determine the long term effect of high levels of radiation on the phosphate ceramic structure.

Status: **Commercially available.**

<u>PROJECT</u>
Argonne is currently involved in a project with Department of Energy (DOE) to demonstrate the Ceramicrete technology on Idaho National Engineering Laboratory (INEL) mixed wastes. As of summer 1997, the facility is under construction and will begin treating wastes in 1998. By September of 1998 the demonstration should be complete. At that time DOE will issue a technology performance report summarizing the efficacy of the technology. Argonne will then be in a position to actively pursue the treatment of commercially generated mixed waste. This technology is currently available for commercial treatment, however Argonne is waiting for DOE’s approval before actively pursuing commercial treatment.

For additional information contact:

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Argonne, IL 60439
630/252-4295

3. ORGANIC DESTRUCTION TECHNOLOGIES

This type of technology treats mixed wastes containing hazardous organic materials contaminated with radionuclides. Since metals can not be destroyed, these technologies do not destroy RCRA metals. The radionuclides generally go through the process unaffected. The treatment product is a waste stream containing radioactives with little or no hazardous organics which simplifies disposal.

3.1 Catalyzed Chemical Oxidation (DETOX)

Technology Description:

PRINCIPLES
DETOX is a chemical process patented by Delphi Research, Inc. that oxidizes and destroys organic compounds. In this process an acidic aqueous solution (3-4%HCl) of iron ions catalytically oxidizes organic chemicals resulting in carbon dioxide and water. The iron ions increase the rate of oxidation by acting as a catalyst in the break down of hazardous organics. Ferric iron ($Fe3+$) oxidizes the organics and is, itself, reduced to ferrous iron ($Fe2+$). Oxygen that is added to the acidic solution converts the ferrous iron back to ferric iron regenerating the iron catalyst for more oxidation reactions. Delphi also has proprietary co-catalysts that can be added to the solution to further accelerate the process.

PROCESS
The acidic process solution is contained within a reaction vessel. This vessel is equipped with several components. They include: a stirring/agitation device which extends down into the process solution; solid and liquid waste feeding systems; and an oxygen supply system. The reaction vessel is a pressurized system which allows the reaction conditions to be modified based on the materials being processed. Waste is added to the vessel via the feeding systems; gases liberated from the process go through a condenser to remove acid gases and water vapor.

RESULT
Organics are destroyed resulting in carbon dioxide and water. Radioactive metals are dissolved and isolated in the acidic process solution. If halogenated organics are being treated, then the process also results in halogen acids.

Because this system works under relatively low temperatures and pressures (below 200 deg C and 70 psi) the off gas is easier to manage and control than in thermal oxidation processes.

Acceptable Wastes:
The following are some informal limits on the characteristics of the waste feeds that this technology can process:
<10% by weight basicity;

< 10% by weight reactive metals;
<5% by weight fluoride, sulfur, phosphorus, calcium and cyanide.

PHASE
This process can treat organic liquids, solids and sludges. This system can process paper, cotton, latex, polyethylene and PVC plastic. It is not suitable for inorganic solids, sludges, debris or soils because these wastes exhaust the oxidizing agent, and increase the solid concentration of the solution beyond saturation. Aqueous stream wastes must also be added slowly to avoid dilution of the reagents.

HAZ
The process is tolerant of wide ranging physical and chemical characteristics of incoming waste. It will treat combustible/organic wastes, halogenated organics and organometallics. Waste streams must have an organic content of 20% or greater for DETOX treatment.

Suitable wastes include:

Aqueous solutions	Organic sludges
Oils	Soft debris
Solvents	Excess chemicals
Combustible solids	

The Department of Energy- Savannah River Site project (see section on status for more information) will treat the following wastes:

Tributyl	Phosphate Trim Sol
Mineral Oil with Lead and Mercury	Hydrocount (surrogate for scintillation fluids)
Toluene	Ethylene Glycol with PCE
Acetone	Organic Liquids with Lead
Combustible solids with Ce and Nd	Oil with Barium and Lead
TCE	Oil with Benzene
TCA	Solvents and Oil with PCB
MeCl2	Paints, Sludges, Solvents

RADS
This information will not be available before the completion of the DOE project.

Status: **Demonstration with Surrogates.**

Delphi has conducted years of bench scale testing on their system. Under an agreement with the Department of Energy, Delphi is constructing a pilot scale system at Savannah River Site (SRS). This system will be the first full scale system of its kind. The pilot will allow Delphi to shake down the system and gather information necessary for designing and constructing a production scale system. The DETOX system at SRS will test hazardous wastes with radioactive surrogates. This phase of testing should be complete after approximately one year, at which time Delphi will pursue testing with actual mixed waste materials.

Delphi is currently looking into commercially applicability of this technology and is interested in identifying potential partners, licensees and users to participate in the commercialization of this technology.

For more information contact:

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702/857-1301

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New Mexico Operations Manager
Delphi Research, Inc.
701 Haines Avenue, NW
Albuquerque, NM 87102
505/243-3111

3.2 Electrochemical Oxidation

Technology Description:

<u>PRINCIPLE</u>

An electrolytic cell is created by placing two electrodes in a process solution. When electricity is run through the system an oxidizing species is generated at the anode. This oxidizing species reacts with organic compounds, destroying them via oxidation.

Researchers at Pacific Northwest National Laboratory (PNNL) are using cerium as the oxidizing species. They call it the mediator. The process solution is composed of cerium nitrate dissolved in nitric acid solution. Los Alamos National Laboratory (LANL) is also researching electrochemical oxidation for mixed waste treatment. They are using a solution of cobalt ions as the process solution. Silver can also be used as the mediator. Although silver is more effective as a oxidizing agent, it is more difficult to work with, as it is a RCRA regulated metal and also forms a precipitate in the presence of chloride ions.

<u>PROCESS</u>

In this technology a mediator is oxidized by creating an electrical potential between two electrodes in a electrolytic cell. The PNNL work uses a process solution of cerium is in its nitrate form. When an electric potential is applied to the solution, cerium is oxidized from an oxidation state of three to an oxidation state of four. This oxidized cerium is capable of reacting with organics and breaking them down.

The mediator in the LANL system is cobalt, which changes from an oxidation state of two to three when an electric potential is applied. The cobalt three is the oxidative species. LANL is also researching electrochemical oxidation for the treatment of non-organic wastes. They can extract and recycle metals, destroy cyanides and reduce nitrates (among other things) using an electrolytic cell.

This process works at low temperatures (less than 100 deg C). As a result, issues concerning volatility are minimized.

<u>RESULTS</u>
Scientists at PNNL and LANL may provide this information.

Acceptable Wastes:

<u>PHASE</u>
Preliminary research at PNNL indicates that this technology will effectively treat organic hazardous wastes with a water content less than 20 or 30%.   This process is capable of treating cellulosic base materials, for example wood and paper. The presence of metals does not influence the process. However, they do build up in the process solution, and must be removed once they have achieved some critical concentration.

<u>HAZ</u>
The PNNL system can destroy organic compounds as well as halogenated organics. LANL's system can destroy some organics as well as treat nitrates, cyanides and metals.

<u>RAD</u>
Contact PNNL for this information. Information from PNNL was not received in the mail by the time this paper was finalized. LANL is just beginning to implement their system on actual mixed waste. For more information, on the radioactives treated with this process, contact them.

Status: **Research Phase.**

Pacific Northwest National Laboratory is pursuing research using cerium nitrate. The research has been going on for a couple of years. They are presently evaluating the success of the technology when used on concentrated organic solutions. Once this work is complete they will begin looking at how mixed waste is treated in this process. PNNL is in the process of seeking patent protection for their invention.

LANL has completed a project treating surrogate mixed wastes. They now are turning their attention to treating actual mixed waste.

For more information, contact:

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509/372-3978

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3.3 Electron Beam Treatment Technology

Technology Description:

PRINCIPLES

HVEA has developed and patented this process to destroy organic chemicals in aqueous stream wastes. The process uses an electron accelerator to generate high energy electrons. When these electrons contact water they create three extremely reactive species: aqueous electrons, hydroxyl radicals, and hydrogen radicals. These three species work together to break down virtually all organics. Aqueous electrons and hydrogen radicals destroy organics through reduction reactions and the hydroxyl radical, a strong oxidizing agent, breaks down organics through oxidation.

PROCESS

Aqueous waste is directed over a weir that causes the waste to flow in thin sheets approximately 4 mm thick. An electron accelerator is used to generate high energy electrons that travel at approximately 97% the speed of light. These electrons are manipulated into a rectangular shape and directed onto the surface of the aqueous waste as it travels over the weir. When the electrons contact the water the three reactive species are created and the organic contaminants are destroyed.

HVEA currently operates a mobile unit. To date, this unit has not been utilized on mixed waste treatment. However, it is a possibility for the future. HVEA does not operate their own treatment facility; they engineer and install the technology on site.

RESULT
This treatment technology destroys the hazardous organic portion of the mixed waste, leaving the radioactive portion in the aqueous stream. The extent to which organics are broken down depends largely on the dose and energy of electrons. With enough energy all organics can be broken down to carbon dioxide, water and salt; however, this is not always necessary. Depending on the original contaminant and the intended use of the product water, treatment could terminate once the organics have been broken to higher oxidation break down products such as aldehydes and ketones.

The radioactives remain in the waste water stream after treatment. The hazardous components have been removed and the resulting water is a low level radioactive waste, simplifying its treatment and disposal. The presence of radionuclides have no effect on the treatment process and simply remain in the waste matrix after treatment.

This treatment technology does not generate any secondary waste streams.

Acceptance Criteria:

PHASE
This technology works on aqueous phase wastes only. It can be applied to slurried soils, sediments and sludges as well, provided they have less than 5%-10% suspended solids.

HAZ
HVEA, Inc has done extensive treatability testing on the following chemicals:

Acenaphthene	Acenaphthylene	Acetic Acid
Acetone	Acetaldehyde	Aniline
Anthracene	AOX	Aroclor1016
Aroclor1221	Aroclor1232	Aroclor1242
Aroclor1248	Aroclor1254	Aroclor1260
Atrazine	Benzene	Benzo(a)anthracene
Benzo(a)flouranthene	Benzo(k)flouranthene	Benzo(a)pyrene
Benzo(g,h,i)perylene	Biphenyl	BOD
Bromodichloromethane	Bromoform	2-Butanone (MEK)
Butryaldehyde	Butyl acetate	Carbazole
Carbon Tetrachloride	Chlorobenzene	2-Chlorobiphenyl
3-Chlorobiphenyl	4-Chlorobiphenyl	Chloroform
2-Chlorophenol	3-Chlorophenol	4-Chlorophenol
Chrysene	COD	o-Cresol
m-Cresol	p-Cresol	DDD
DDE	DDT	Dibenzo(a,h)anthracene
Dibromochloromethane	DBCP	EDB
1,2-Dichlorobenzene	1,3-Dichlorobenzene	1,4-Dichlorobenzene

2,2'-Dichlorobiphenyl	4,4'-Dichlorobiphenyl	1,1-Dichloroethane
1,2-Dichloroethane	1,1-Dichloroethylene	cis-1,2-Dichloroethylene
trans-1,2-Dichloroethylene	2,4-Dichlorophenol	2,6-Dichlorophenol
1,2-Dichloropropane	1,3-Dichloropropane	2,4-D
cis-1,3-Dichloropropene	trans-1,3-Dichloropropene	Dieldrin
Dimethylether	DEMP	m-Dihydroxyphenol
o-Dihydroxyphenol	p-Dihyroxyphenol	Diisopropylbenzene
DIMP	DMMP	2,4-Dimethylphenol
1,4-Dioxane	Ethylbenzene	Endrin
Flouranthene	Fluorene	Formaldehyde
Formic Acid	Glyoxal	alpha-HCH
beta-HCH	gamma-HCH	Lindane
2,2',3,4,4',5,5'-Heptachlorobiphenyl		Hexachlorobenzene
2,2',4,4',5,5'-Hexachlorobiphenyl		2,2',3,4,4',5'-Hexachlorobiphenyl
Hexachloro-1,3-butadiene	Hexachloroethane	Ideno(1,2,3-cd)pyrene
Methanol	Methylene Chloride	Methylglyoxal Methylhydroperoxide
4-Methylphenol	Methylphosphonic Acid	Methylstryene
Naphthalene	Nitrobenzene	
Nitrocellulose	Nitroguanadine	2-Nitrophenol
3-Nitrophenol	4-Nitrophenol	Phenanthrene
2,2',4,5,5'-Pentachlorobiphenyl		Pentachlorobiphenyl
Phenol	Propionaldehyde	Pyrene
Pyridine	RDX	Simazine
Sytrene	1,2,3,5-Tetrachlorobenzene	1,2,4,5-Tetrachlorobenzene
2,2',5,5'-Tetrachlorobiphenyl	1,1,1,2-Tetrachloroethane	PCE
Toluidine	Toluene	1,2,4-Trichlorobenzene
2,4,4'-Trichlorobiphenyl	1,1,1-Trichloroethane	1,1,2-Trichloroethane
TCE	TNT	Vinyl Chloride
m-Xylene	o-Xylene	p-Xylene

<u>RAD</u>

Since the effectiveness of this process is independent of the presence of radionuclides, this process should be capable of treating all types of radionuclides. However, HVEA, Inc would have to address the health and safety issues associated with treating high level radioactives.

Status: **Demonstration with Surrogates.**

In 1996 HVEA complete a project with the Department of Energy, Savannah River Site. This project, which tested the HVEA electron beam technology on a simulated waste stream, was divided into two phases. Phase one involved design and testing of a bench scale model of the system. Phase two included the construction of a large scale system capable of treating 2,000 to 3,000 gallons of waste. Since this work has been completed, HVEA has not entered into additional mixed waste treatability projects.

Although HVEA does not operate a facility, the technology has proven successful for mixed waste treatment. They are prepared for treatment of commercially generated mixed waste.

For more information contact:

High Voltage Environmental Applications, Inc. (HVEA, Inc.)
PO Box 14-4120
Coral Gables, Florida
33114-1420
305/443-7791

3.4 Gas Phase Reduction/Eco Logic Process

Technology Description:

PRINCIPLE

The gas phase reduction process is patented by ELI Eco Logic International, Inc. This process breaks down organics using a hydrogenolysis reaction. In this reaction alkyl groups and halides on long chain carbon molecules are replaced by hydrogen atoms. This means that long chain hydrocarbons are broken down to shorter chain hydrocarbons and the bonding sites that used to be occupied by the adjacent carbon atom are now occupied by a hydrogen atom. The result is a hydrogen rich methane gas product that can be used for its energy content.

PROCESS

Before treatment, wastes must be atomized into a gaseous or vapor state. Therefore, solids and liquids must be separated. As a result, for the treatment of mixed wastes, this technology is actually two technologies connected in series. Eco Logic uses thermal desorption as well as autoclaving equipment to separate the solids and liquids. The vaporized organics go into the gas phase reduction vessel and the radionuclides are left behind in their solid form.

After separation the organics are vaporized to a gaseous state. The vaporized waste is then pre-heated, mixed with hydrogen gas and injected into a special reaction vessel. As the waste/hydrogen mixture makes its way from the top to the bottom of the vessel it is heated by electrical heating elements. Once the mixture is heated to approximately 850-950 deg C, it begins to undergo hydrogenolysis.

Since much of the off gas can be recycled back into the system, the Eco Logic process is a fairly compact structure. As a result, Eco Logic is able to offer this treatment technology as either a permanent fixture or a mobile treatment system.

RESULTS

The break down of organic materials results in a hydrogen rich methane gas product that contains approximately 60% hydrogen, 30% methane as well as ethylene, nitrogen, carbon monoxide and water vapor. Up to 95% of the off gas can be recycled back into the process. Eco Logic compresses and stores excess gas product in cylinders. If this compressed gas meets regulations, Eco Logic can use it 1) in their boilers as a source of energy, 2) as a front end additive for the treatment process, or 3) as a reactant with water to create hydrogen for the process. If organo-halides are present in the waste feed, the process will also generate acid gases which can be removed with a gas treatment system.

Most of the radioactives are left behind in their solid state after the thermal desorption treatment. Those radionuclides that are easily volatilized are caught in the off gas treatment system.

Acceptance Criteria:

PHASE

Liquid and aqueous wastes are easily treated by injection directly into the reactor. Treatment of organically contaminated slurries, sludges, and solid matrices is more difficult. These substances must first be desorbed to separate the organic contaminants from the solids and inorganics. Once desorbed the organics are in their gaseous form and ready for injection into the system.

HAZ

This treatment system can destroy many organic and halogenated organic contaminants, including but not limited to: PCBs, dioxins, polyaromatic hydrocarbons, chlorophenol and pesticides. This system does not treat inorganic hazardous materials, such as RCRA metals.

RAD

Treatability information on radioactives will be determined during the Morgantown Department of Energy demonstration which is summarized below.

Status: **Demonstration with Surrogates.**

The Eco Logic process is fully operational for the treatment of hazardous wastes, but is still in the works for mixed waste. In 1996 Eco Logic and Scientific Applications International Corporation (SAIC) received a contract from DOE=s Morgantown Energy Technology Center to demonstrate their technology on low level radioactive wastes. In 1997 they are planning to perform treatability testing on hazardous materials with radioactive surrogates. The success of this project will enable Eco Logic to determine if this is a commercially viable technology.

For more information contact:

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3.5 Steam Reforming

Technology Description:

PROCESS
Steam reforming destroys the hazardous organic portion of mixed waste by exposing it to high temperature steam. The process occurs in two phases. In the first phase waste streams are exposed to steam at moderate temperatures. This volatilizes the organic components and separates them from the inorganic components of the waste stream (similar to thermal desorption). The volatilized organics are transported to another reaction chamber for the second phase treatment, where the gaseous organics are exposed to very high temperature steam, which destroys the organic compounds. The radioisotopes remain in the primary reaction chamber in their solid form.

Research identified two organizations pursuing this technology. They are: ThermoChem/Manufacturing and Technology Conversion International; and Scientific Ecology Group (SEG).

RESULT
Organics are separated from the radionuclides and destroyed, resulting in an off gas stream of carbon monoxide, carbon dioxide, hydrogen gas and water. Acid gases are formed if the organics were halogenated.

The radioactive components are separated from the organics and remain in their solid form in the phase one reaction vessel. Cesium, one of the most easily volatilized radionuclides, can be retained in its solid form if temperatures in the primary reaction chamber are properly set. This process alone does not result in a stable final waste form for the radioisotopes.

Acceptable Wastes:

PHASE

This process can successfully treat solids, sludges, liquids and aqueous waste streams. SEG is currently conducting research on extraction and treatment of organics from debris materials, including cellulose and plastic wastes.

HAZ

This system is capable of separating and destroying waste streams including concentrated or pure organics. The presence of metals does not interfere with the treatment process. ThermoChem has complete tests on naphthalene, 1,2-Dichlorobenzene, chromium, nickel, lead, cadmium.

Scientific Ecology Group, Inc has performed treatability studies on (Note: this is not necessarily a complete list.):

Acenaphthene	Acenaphthylene
Acetone	Anthracene
Arsenic	Benzo(a)anthracene
Benzo(b+k)flouranthene	Benzo(g,h,i)perylene
Benzo(a)pyrene	Carbon Tetrachloride
Chloroform	Chromium
Chrysene	Copper
Dibenzo(A,H)anthracene	Dichlorobenzene
Flouranthene	Fluorene
Ideno(1,2,3,cd)pyrene	Isopropanol
Methanol	Methyl Isobutyl Ketone
Methylene Chloride	Naphthalene
Pentachlorophenol	Phenanthrene
Pyrene	1,1,1-Trichloroethane
Xylene	

RAD

As of summer 1997, ThermoChem/MTCI was involved in research on surrogate radioactive wastes, not actual waste streams. As a result, their information on treatable radioisotopes is limited. They have conducted research on cerium chloride ($CeCl_3$), cesium chloride (CsCl) and cesium nitrate ($CsNO_3$).

SEG company materials indicate their system has successfully treated pharmaceutical wastes that contained carbon-14, tritium, and medical isotopes such as sulfur, phosphorous, barium, and potassium. They have also treated wastes containing uranium, plutonium and cesium. Although it is possible, the treatment of radio-labeled carbon and tritium can pose a difficult challenge for steam reforming. These materials are volatilized and liberated into the off gas system, and therefore, do not result in a convenient final waste form for those radioactives.

Status: **Demonstration with Surrogates.**

Research turned up two organizations that are pursuing this technology for mixed waste treatment. These organizations are ThermoChem/Manufacturing and Technology Conversion International (MTCI) and Scientific Ecology Group (SEG), Inc a division of GTS Duratek. This may not be an exhaustive list of organizations involved in steam reforming technology development.

PROJECTS

ThermoChem/MTCI has been awarded a contract to demonstrate their technology for the Department of Energy. The organization constructed a pilot scale facility in Baltimore, Maryland where they have performed extensive treatability testing on surrogates for DOE mixed waste; ThermoChem is presently preparing a report on this project. This project will aid them in determining the viability of this technology and how to proceed with its commercialization. As of summer 1997, ThermoChem/MTCI has not made this technology available for treatment of commercially generated waste.

SEG owns a full scale facility in Oak Ridge, Tennessee. This facility has been used for the volume reduction of low level radioactive wastes mixed with non-RCRA organics. The facility has an NRC license, but no RCRA permit. As a result, this facility can not process mixed wastes. SEG is currently evaluating the option of obtaining a RCRA part B permit for the treatment of hazardous wastes.

For more information, contact:

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Scientific Ecology Group/GTS Duratek, Inc.
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423/376-8321

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SEG/Duratek Headquarters:
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Columbia, MD 21046

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ThermoChem, Inc.
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3.6 Super Critical Water Oxidation

Technology Description:

PRINCIPLES
Supercritical water describes a state of water that has been heated above its critical temperature (374 deg C) and compressed greater than its critical pressure (221 bar). The high temperature favors the gas phase and the high pressure favors the liquid phase. As a result, supercritical water is a non-polar fluid in which the gas and liquid phases are indistinguishable from each other. These are the characteristics that make supercritical water an excellent solvent for both organic compounds and oxygen.

The supercritical water oxidation (SCWO) process destroys the hazardous organic portion of wastes via oxidation. By dissolving both organics and oxygen (or an alternate oxidizing agent) in the same fluid, problems associated with mixing (i.e. making sure the two reactants interact with each other) are completely eliminated. In two-phase oxidation reactions, reaction rates are limited by mass transfer; in SCWO both reagents are in the same phase, therefore the reaction rate is limited by kinetics. As a result, the reactions are much faster.

PROCESS
The waste stream is pre-heated (often by mixing with recycled effluent), pressurized and injected into the SCWO chamber, which is an air tight vessel capable of containing very high pressures. Oxygen, hydrogen peroxide, or another oxidizing agent is also injected into the reaction vessel. The oxidizing agent and the organic wastes become dissolved in the supercritical water where they interact and undergo oxidation reactions. This reaction results in carbon dioxide and water. Any halogens that were attached to organic species are retained in the supercritical fluid in their acid form. Most metals and radionuclides are oxidized and form a precipitate. The precipitated metal oxides and radionuclides are sub micron in size. As a result, they stay suspended in solution and are carried out of the system with the water. These solids can then be separated out of the process solution via filtration.

The process effluents go through a solid separator system, as well as systems to separate the liquids from the gases.

RESULTS
The destruction of the organics results in carbon dioxide, water and other innocuous compounds. This gas is quite clean and needs little treatment for two reasons. First of all, this process results in few incomplete combustion products, and second, acids and most metal oxides stay in solution in the supercritical water.

Metals and radionuclides can react with oxygen and form oxides which are carried with the process water through the system. The radioactives can be separated from the water by evaporation or filtration.

Acceptable Wastes:

PHASE

This technology can process aqueous waste streams with an organic content of 10% or less. Most liquid waste streams are easily treated by injecting them into the oxidation vessel. Solid waste is more of a challenge and requires some pre-treatment work. At Los Alamos National Laboratory they have devised several ways to manage solids. The solids are either ground down to approximately 1 millimeter in size, slurried with water and injected into the system or pyrolized to a low-melting organic liquid which is then pumped through the system.

HAZ

According to American Chemical Society and Los Alamos National Laboratory SCWO has successfully treated the following materials:

Acetic Acid	Ammonia
Aroclocs (PCBs)	Benzene
Biphenyl	Butanol
Carbon Tetrachloride	Carboxylic Acid
Carboxymethyl Cellulose	Cellulose
Chlorinated Dibenzo-p-dioxins	Chlorobenzene
Chloroform	2-Chlorophenol
o-Chlorotoluene	Cyanide
Cyclohexane	DDT
Decachlorobiphenyl	Dextrose
Dibenzofurans	3,5-Dibromo-N-cyclohexyl-n-methyltoluene- ,2-diamide
Dibutyl Phosphate	Dichloroacetic Acid
Dichloroanisole	Dichlorobenzene
4,4'-Dichlorobiphenyl	1,2-Dichloroehtylene
Dichlorophenol	Dimethyl Sulfoxide
Dimethylformamide	4,6-Dinitro-o-cresol
2,4-Dinitrotoluene	Dipryridamole
Ethanol	Ethyl Acetate
Ethylene Chlorohydrin	Ethylene Glycol
Ehtylenediamine Tetraacetic Acid	Fluorescein
Hexachlorobenzene	Hexachlorocyclohexane
Hexachloropentadiene	Isooctane
Isopropanol	Methanol
Methyl Cellulose	Methylene Chloride
Methyl Ethyl Ketone	Nitrobenzene
2-Nitrophenol	4-Nitrophenol
Nitrotoluene	Octachlorostyrene
Octadecanoic Acid Mg Salt	Pentachlorobenzene
Pentachlorobenzonitrile	Pentachloropyridine
Phenol	Sodium Hexanoate
Sodium Propionate	Sucrose
Tetrachlorobenzene	Tetrachloroethylene

Tetrapropylene H	Toluene
Tributyl Phosphate	Trichlorobenzenes
1,1,1-Trichloroethane	1,1,2-Trichloroethane
Trichloroethylene	Trichlorophenol
Trifluoroacetic Acid	1,3,7-Trimethylxanthine
Urea	O-Xylene

Chemical warfare agents, rocket motors and explosives.

RAD
This system is capable of treating most radionuclides. However, radioactive oxygen, carbon, nitrogen and tritium are not suitable for treatment by this process, as they could result in large amounts of radioactively contaminated gas and/or water.

Status: **Bench Scale.**

INEL: -- Project terminated.
From 1993-1995 INEL conducted an aggressive research effort to determine the applicability of supercritical water oxidation to DOE wastes. In mid 1995 this project was terminated as result of few technological advances.

LANL: -- Bench scale testing.
In 1995 Los Alamos National Laboratory (LANL) received funding from EM50 to research SCWO for their own wastes. Presently, they have built a small reactor that can process up to 3.6 kg of waste per hour. In early September 1997, DOE will make the final safety assessment. The system will begin operating, treating mixed waste generated at LANL which is presently stored on site.

Once bench scale operations are complete LANL, will assess this technology for a permanent fixture on site. LANL is planning a 95% reduction in waste shipped off site for treatment and disposal. A Supercritical water oxidation system may be installed on site to help achieve this goal.

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4. COMBINATION TECHNOLOGIES

Combination technologies are any technologies that do a combination of the above. The two technologies included in this section destroy the organic portion and immobilize the radioactive portion of the waste in a stable final waste form.

4.1 Quantum-Catalytic Extraction Processing (Q-CEP)

Technology Description:

PRINCIPLES
The Quantum CEP is patented by Molten Metal Technology. This treatment process is comprised of two phases: catalytic dissociation and product synthesis. In the catalytic dissociation phase a molten metal bath of iron or nickel is used to break down compounds into their elemental components. Although the process operates at around 3,000° F, thermal destruction is not the primary means of treatment. Instead, the metal bath works as a catalyst, breaking down compounds to their elemental components by providing a lower energy intermediate in the form of an iron-element complex for the liberated elements. Once compounds are broken down to their component elements the conditions inside the reaction vessel can be manipulated and additional reagents can be added so that the intermediate species form new and usable products that can be recycled.

PROCESS
Waste is sent to the MMT Technology Center in Oak Ridge, TN. The Tech Center houses several Q-CEP systems with varying size and capacity. Each system contains iron in its solid form. The iron is heated by induction heating until it becomes molten. At that time waste is added to the molten metal bath. Gases, fine solids, pumpable liquids and slurries are bottom fed into the reactor; shreddable solids enter the bath via lances from the top of the reaction vessel; non-shreddable and bulk solids are fed with baffles and lances. Once inside the reactor the wastes become dissolved in the molten bath. Molecules are broken down to their components with the carbon and hydrogen being released as gas and the inorganic constituents remaining dissolved in the metal bath or creating a molten ceramic slag that floats on top of the metal.

RESULT
Radioactive metals are sequestered in the molten bath or in the ceramic slag floating on top. Both are stable final waste forms. Some of the more easily volatilized metals are vaporized during the process and captured in the off gas treatment system.

Hazardous materials are broken down into carbon and hydrogen which are released from the metal bath as carbon monoxide and hydrogen gas. These can be sequestered for industrial use. Chlorine from the destruction of organochlorides can be recovered in the form of HCl.

Acceptable Wastes:

PHASE

The Q-CEP is a very robust system and can process many forms of mixed waste including gases, liquids, slurries, and shreddable, as well as bulk, solids.

HAZ

Q-CEP can process organic, organometallic, and inorganic wastes. As mentioned above this system is quite robust and is capable of treating a wide range of hazardous materials. Company materials indicate that Q-CEP has successfully processed the following hazardous materials:

Spent metal and electrical components (SMC),
Chlorinated waste streams
And the listed wastes:

F024... Process wastes including but not limited to, distillation residues, heavy ends, tars, and reactor clean-out wastes, from the production of certain chlorinated aliphatic hydrocarbons (with chain lengths from one to and including five with varying amounts and positions of chlorine substitution) by free radical catalyzed processes.

K019...Heavy end from the distillation of ethylene dichloride in ethylene dichloride production.

K020...Heavy ends from the distillation of vinyl chloride in vinyl chloride monomer production.

K027...Centrifuge and distillation residues from toluene diisocyanate production.

Q-CEP is the BDAT equivalent for:

K112... Reaction by-product water from the drying column in the production of toluenediamine via hydrogenation of dinitrotoluene.

K113...Condensed liquid light ends from the purification of toluenediamine in the production of toluenediamine via hydrogenation of dinitrotoluene.

K114...Vicinals from the purification of toluenediamine via hydrogenation of dinitrotoluene.

K115...Heavy ends from the purification of toluenediamine via hydrogenation of dinitrotoluene.

K116...Organic condensate from the solvent recovery column in the production of toluene diisocyanate via phosgenation of toluenediamine.

U221...Toluenediamine

U223...Toluene diisocyanate

This is not an exhaustive list of materials that can be treated with the Q-CEP process. A representative of Molten Metal Technology speculates that this system can treat approximately 80% of all listed wastes.

RAD
Q-CEP can process mixed wastes containing radionuclides with atomic numbers 1-98 that measure less than 10 rem per hour.

Status: **Commercially available.**

MMT currently operates a facility which accepts mixed waste in Oak Ridge, TN. This facility, called the MMT Technology Center, is a designated recycling operation. Extensive research has been conducted at the site and the facility will be operational with commercially generated mixed waste in the summer of 1997.

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4.2 Plasma Vitrification

Technology Description:

PRINCIPLES
Plasma is the fourth state of matter characterized by an electrically neutral, highly ionized gas made up of ions, electrons and neutral particles. Plasma gas exists at a very high temperature typically in excess of 1,000° C. The intense heat of plasma destroys organic contaminants and melts inorganics into a molten ceramic slag. Inorganics and other non-combustibles become trapped in the molten slag which solidifies into a stable final waste form once cooled. Fluxes and ceramic materials can be added to the waste streams prior to treatment to ensure that there is ample inorganic material to create a bath of molten slag.

PROCESS
There are several organizations researching and developing this type of technology. Each system has its own specific characteristics. For the most part, the systems all use an inert gas to carry an electric current. The resistance of the gas to the current heats and ionizes the gas, resulting in plasma. The plasma gas is then applied to the waste material to be treated.

EPI/Svedala use an electrode that is suspended above the waste/melt and can be lowered and raised mechanically. This allows for better temperature control of the atmosphere in the reaction vessel. The Retech system includes a plasma torch and rotating treatment vessel to maximize mixing and exposure to the torch. Other systems include PEAT, Inc and Duratek, Inc.

<u>RESULTS</u>
The organic hazardous components are oxidized to carbon dioxide and water. The radionuclides are trapped inside the ceramic, which becomes a stable final waste form once it cools and solidifies.

Because these systems operate on principles similar to incineration, like incinerators they often require extensive off gas treatment systems. The easily volatilized radionuclide, cesium, is a particular problem for thermal treatment systems and often must be captured in the off gas system.

Acceptable Wastes:
Plasma vitrification is a group of technologies, not an individual technology. As a result, the information provided here on acceptable wastes is necessarily general. The following section gives a general information on the wastes that can be treated with this system, however, the technology developer must be contacted for more detailed information.

<u>PHASE</u>
Most of these types of technology can process solid, liquid and gas waste streams.

<u>HAZ</u>
These systems are capable of treating organic as well as inorganic waste streams, and are particularly effective on waste streams that are a mixture of both.

<u>RAD</u>
For more information in this category, each individual vendor must be contacted.

Status: **Commercially available.**

This technology is currently available from Retech, Inc and EPI/Svedala, Inc. Both engineer and install the technology on site; neither organization operates a treatment facility. They may, however, be operating a mobile unit. PEAT, Inc and Duratek, Inc are also doing work on vitrification of mixed waste.

<u>PROJECTS</u>
Plasma vitrification has been used at many sites and has been designated a BDAT (best developed available technology) by the EPA for the treatment of high level radioactive waste. Retech's system was used at INEL Pit 9; EPI has demonstrated their technology at Savannah River Site on

their mixed waste as well as INEL contaminated soils**.**

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